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Study on the structural behavior of precast concrete dapped-end beams with different reinforcement details

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ABSTRACT
This paper describes the behavior of dapped ends of precast concrete beams based on an experimental program conducted to investigate the influence of detailing on the behavior of dapped ends. Experimental research findings presented in this paper

Each end of four reinforced concrete dapped end beams with eight ends were tested to failure (8 tests in total) eight different reinforcement schemes were investigated in the experimental program: the PCI-1, PCI-2, Inclined As with welded plate, inclined As with Practical anchorage, inclined As with proper anchorage, 200% As with 50% Ash, 200% Ash with 50% As, and practical details, . The experimental program examined the anchorage, details of hanger steel and longitudinal reinforcement believed to affect the behavior. The experimental results indicated that the extent of cracking, the ultimate strength, and the failure mode are influenced by the reinforcement arrangement at the dapped end. Addition to simulate a nonlinear analysis using the finite element package ANSYS and the analytical results compared.

Keywords: Behavior; reinforcement schemes; ultimate; dapped ends

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I. INTRODUCTION

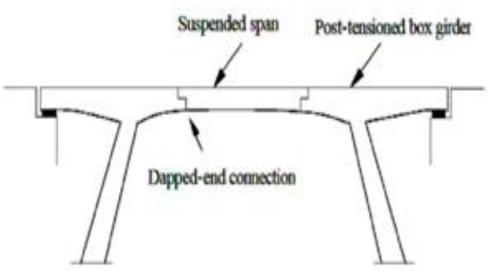
A dapped beam relies on a reduced section to support the member. The notch itself is known as the dap, and the reduced concrete section remaining above the dap is referred to as the nib. **Figure 1** shows a dapped-end connection typically used for parking structures.

The design and construction of dapped end beams is challenging for several reasons. The strength of a dapped end depends on the anchorage, details of hanger steel and longitudinal reinforcement.

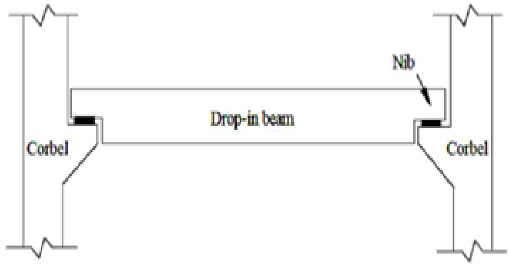
Design of the nib requires consideration of high shear stresses, which are greater than elsewhere in the member.

In many respects the nib of a dapped end look a lot like an inverted corbel. However, in the case of the corbel, the inclined concrete compression force in the corbel is resisted by a compression force in the column (Fig. Ia); but in the case of the dapped end, the inclined compression force in the nib must be resisted by a tension force in the stirrup reinforcement.

In some cases, the cracks may be attributed to poor design or construction practices. HoweverEnough reinforcement must cross these cracks to prevent failure.



a. Cantilever suspended span bridge



b. Drop-in-Beam supported byCorbels

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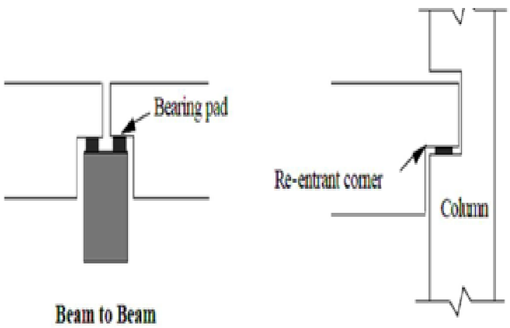


c. Hide Away typeconnections

Fig. 1: Some typical applications of dapped ended beams in pre-cast structures

The current design procedure for dapped-end connections, outlined in the seventh edition of the PCI Design Hand- book: Precast and Prestressed Concrete,1 is based on the research of Mattock and Chan.2 The design method is based on the equilibrium of forces acting across potential failure planes and conservatively treats the dapped-end details as reinforced concrete inverted corbel details.

The PCI Design Handbook illustrates typical dapped-end reinforcement details and potential failure planes that have been observed in dapped double-tee beams (Fig. 2). The bars labeled Ash are referred to as hanger reinforcement,

with anchorage provided by the horizontal extension A'

bent toward the full-depth section of the beam. The hanger reinforcement serves to transfer the vertical reaction at the nib to the full section of the beam and to resist the diagonal tension cracking from the reentrant corner (crack 3) andin the full-depth section (crack 5) (top of Fig. 2). The bars labeled As are referred to as nib flexural reinforcement and are required for resisting the cantilever bending and axialtension in the nib. The PCI Design Handbook requires that the As and Ash ' reinforcement be extended past the critical

diagonal crack failure plane indicated as crack 5, a distance that cannot be less than the development length of the barsℓd. The bars labeled Ah and Av are required for resisting the diagonal tension cracking in the nib indicated as crack 4.

II. LITERATURE REVIEW

Experimental Investigation

Test matrix for the experimental program

Beam	Dapped-end No.	As (Main RFT)		Ash (Vertical Bars)		Av	Ah
Sample 1	1L	2T10	Inclined U bar with proper anchorage	1T16	L Bar	2T10 closed stirrups	-
	1R	2T10	Inclined U bar with Practical anchorage	1T12+1T10	closed stirrups with spacing 50mm	2T10 closed stirrups	-
Sample 2	2L	4T10	welded to steel plate	2T16	C shaped bars	2T10 closed stirrups	1T10 U-bar
	2R	4T10	welded to steel plate	1T12+1T10	closed stirrups with spacing 50mm	2T10 closed stirrups	1T10 U-bar
Sample 3	3L	2T16	U bars with development length beyond crack no 5 (2 As)	1T10	closed stirrups (0.5 Ash)	2T10 closed stirrups	2T10 U-Bars

	3R	1T10	U bars (0.5 As)	2T16	closed stirrups with spacing 50mm (2 Ash)	2T10 closed stirrups	1T10 U-bar
Sample 4	**4L**	2T10	U bars	2T16	L Bar	2T10 closed stirrups	1T10 U-Bars
	4R	2T10	Inclined U bar with welded steel plate for anchorage	1T12+1T10	closed stirrups with spacing 50mm	2T10 closed stirrups	-
Av=Nib Vertical Shear Reinforcement Ah=Nib Shear Friction Reinforcement As=Nib Flexure Reinforcement Ash=Hanger Reinforcement							

While the design of dapped-end beams typically follows the current PCI Design Handbook procedure, field performance remains a concern and dapped-end reinforcement details are not yet standardized within the industry. The research findings are reported in this papers which describes the experimental program under which promising reinforcement schemes, the development of design guidelines for the dapped ends of precast beams member. The research report[7] provides additional background and research findings on dapped thin-stemmed members, including a literature review, industry experience, the analytical study, and an auxiliary experimental program to study the behavior of the lap splice between the hanger reinforcement

Experimental program

The experimental program was developed based on the results of three-dimensional nonlinear finite element models. The testing program consisted of eight dapped-end beams with different reinforcement schemes for the dapped ends. All beams had a cross section corresponding to a (400 mm) deep, (200 mm) wide and 2m long. **Figure 3** shows the cross section of the tested specimens. Each dapped end was tested to failure in a separate test. After testing one end of a beam, the beam was rotated to test the other end.

The experimental program examined the performance of eight different reinforcement schemes and the influence of these parameters that have shown significant behavioral effects based on finite element analyses. **Table 1**summarizes the test matrix of the experimental program.

The two ends of each beam are designated by the sides as shown in section elevation L (left) and R (right). Table 1 indicates the dap reinforcement used for each specimen. Complete reinforcement details of all eight tested dapped ends are available in appendix A of the research report.[7]

the loads were gradually increased and the cracking pattern and corresponding loads were recorded. The beams were loaded till failure.

Materials:

Mix Parameters		**Design**
Grade 28days [fc]	(N/ mm^2)	**40**
W/C Ratio	(Max.)	**0.37**
Cement Content	(Min. kg/m^3)	**256 + 144=400**

Type Of Cement	**OPC + 36% GGBS**	
Fresh Concrete Properties	**Test Method**	**Specification Limits**
Slump at the point of delivery	BS EN 12350-2	**175 ± 25mm**
Temperature at placing (Max. °C)	DMS-026-2018	**35**
Entrapped air content (Max. %)	BS EN 12350-7	**2**
Durability Properties		
Rapid Chloride Permeability @ 28 days	**3000(Max. coulombs)**	
Water absorption @ 28 days	**2(Max. %)**	
Water permeability @ 28 days	**15(Max. mm)**	
Initial Surface Absorption Test @ 28 days	**0.22(Max. ml/m2/s)**	

Mixture Proportion					
Mix Components	**S.G.**	**Abs. (%)**	**SSD Wt (kg)**	**Dry Wt (kg)**	**Volume (kg)**
Ordinary Portland Cement	3.08		**256**	**256**	0.083
Ground-granulated blast-furnace slag (GGBS)	2.77		**144**	**144**	0.052
Water	1		**150**	**163**	0.149
20mm Crushed Agg.	2.77	0.7	**615**	**611**	0.222
10mm Crushed Agg.	2.74	0.3	**440**	**439**	0.161
0-5mm Crushed Sand	2.73	0.6	**534**	**531**	0.196

Dune Sand	2.67	1.3	**298**	**294**	0.112
EPSILONE WR222F	1.06		**6**	**6**	0.006
Entrapped air content (%)	2				0.02
Total per m³			**2443**	**2443**	**1**

Reinforcement schemes

The PCI 7th edtion show the reinforcement requirements as below

The flexure and axial tension in the nib.

$As = [Vu * (a/d) + Nu * (h/d)] / (\varphi * fy)$ (1)

Where

$Vu = P$; φ = strength reduction factor = 0.75; & assumed that Nu = 0

2. Direct shear

$As = (2 * Vu)/(3 * \varphi * fy * \mu e) + (Nu/(\varphi * fy)$ (2)

$\mu e = (1000 * \varphi * \lambda * b * h * \mu)/Vu$ (3)

Where $\mu e \leq 3.4$; $\lambda = 1$ for normal weight concrete; and

μ = shear − frictioncoefficient $= 1.4 * \lambda$

3. Hanger reinforcement for diagonal tension at reentrant corner

$Ash = \frac{TBC}{}(\varphi * fyp)$ EQ 1. 1 (4)

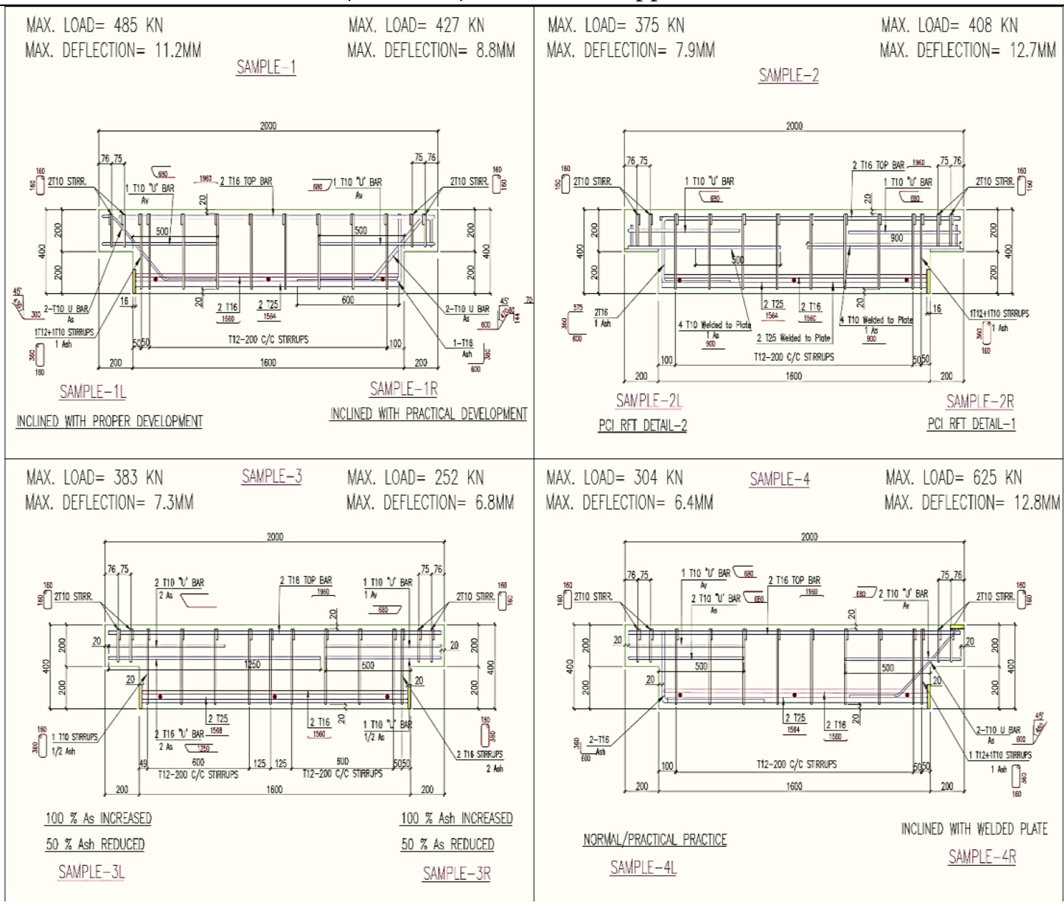
WhereTBC = Vu = P; andfyp = theyieldstressofhangerreinforcement

4. Diagonal tension in the nib

$Av = [(Vu/\varphi) - 2 * \lambda * b * d * \sqrt{fc'}]/(2 * fyv)$ (5)

fyv = the yield stress of vertical reinforcement in the nib

The eight reinforcement schemes included in this experimental program were thePCI-1, PCI-2, Inclined As with welded plate, inclined As with Practical anchorage, inclined As with proper anchorage, 200% As with 50% Ash, 200% Ash with 50% As ,and practical details. **Figure 4** shows the reinforcement details for each of the eight schemes. Dapped-end reinforcement for all eight schemes were designed as per PCI equations to have the same area of steel for flexure reinforcement, hanger reinforcement and other dapped-end reinforcing steel, allowing for comparison of the performances of the eight schemes.



Sample-2(control)

were designed and detailed based on the PCI Design Handbook (PCI, 7th Edition). The Left (2L) end used Two T 16 vertical hanger (Ash) reinforcement which was anchored by horizontal bends at the top and bottom (see Fig. 2.4). The anchorage of the bottom flexural bars at the Right & Left ends was provided by Two T25 horizontal bars welded to a 150 x 200 x 12 mm steel plate. Photographs of the reinforcing steel details are shown in Figs. 2.20 to 2.25. The bottom flexural tension reinforcement consists of 2 T25 plus 2 T16 reinforcing bars along the length of the full-depth beam.one T12 &one T10stirrupswereusedtoprovidetherequiredcapacityforthemainverticaltensionhanger(Ash)andhadthesameareaastheverticaltensiontieattheRightends.IntherestoftheshearspanTheT12doubleleggedclosedstirrupswerespacedat200mmattheRight&Leftends. TwoT16topbarswereusedtoanchorthestirrups.ForthehorizontaltensiontieA$_S$,four T10barswereusedandextendeda distanceofL$_d$beyondtheassumedanchorpoint. In addition,thesefourT10barswereweldedtoasteelplate 200 x 200 x 10 foranchorage also two T16 short bars welded to the steel plate for anchorage.One T10horizontalU-bars(Ah) wereplacedparallelto the primary tensile tie reinforcement in the region above the support to provide crack control. Thehorizontal lU-barsinthenibwereheldinplacebytwo T10verticalstirrups immediately above thesupport.

Specimen (Sample-1)

The Sample 1L reinforcement As provided to determine whether the inclined bars with proper anchorage could add more shear capacity than PCI standard reinforcement details

1L was changing the shape of main reinforcement As from straight bars welded to steel plate (as control Beam PCI detail) to inclined bar bent at top to get proper anchorage which was difficult to adjust the shape with this complicated bar shape. and used 1T10 U bar at the bottom of extended end to catch the stirrups , for vertical bars Ash was using 1 T16 L shaped bar and no Ah used in this side **Figures 2.5**, **The Sample 1R reinforcement As provided to determine whether the inclined bars with practical anchorage could vary the shear capacity than RFT details of sample 1L**

In Sample 1R was changing the shape of main reinforcement As to inclined bar slightly bent at top to get practical anchorage which was easy to manufacture , for vertical bars Ash was using 1 T12 + 1 T10 as closed stirrups closed to the reentrant corner **Figures 2.5**

Specimen (Sample-3)

The Sample 3L reinforcement As provided 200% the required amount as per PCI equations and also the amount of hanger reinforcement decreased 50 % to determine whether As or Ash has the more affect to determine whether the amount of hanger reinforcement could be reducedin Sample 3L was increasing As from 4 t10 straight bars welded to steel plate (as per control specimen PCI detail) to 2As 2 T16 U bars at the bottom of extended end to catch the stirrups and extended 800mm beyond crack 5 , for vertical bars Ash was using 2 T16 as closed stirrups closed to the reentrant corner and Ah was used 2 T10 U bars **Figures 2.5**, **The Sample 3R reinforcement As provided 50% the required amount as per PCI equations and also the amount of hanger reinforcement increased to 200 % to determine whether As or Ash has the more affect**

in Sample 3R was decreasing As to half amount 1 T10 U bar at the bottom of extended end, for vertical bars Ash was increased to 2 T16 as closed stirrups closed to the reentrant corner and Ah was used 1T10 U bar **Figures 2.6**

Specimen (Sample-4)

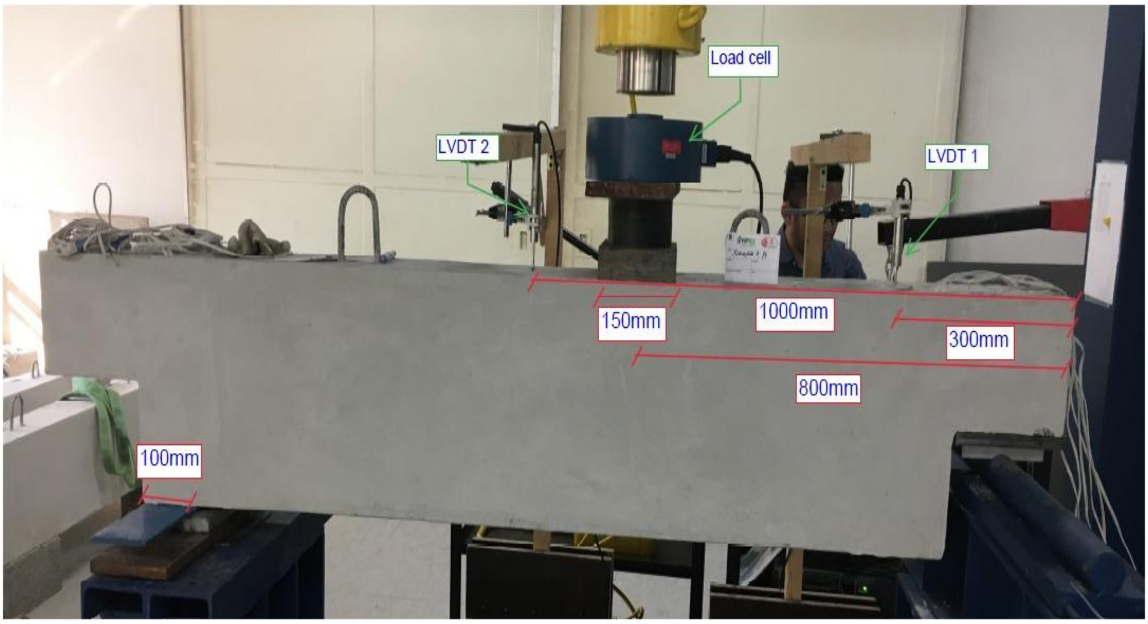
The Sample 4L reinforcementAs provided to determine whether the inclined bars with welded plate could vary the shear capacity than RFT details of sample 1

In Sample 4L was changing As from 4 T10 straight bars welded to steel plate(as control specimen PCI detail) to 2 T10 U bars at the bottom of extended end to catch the stirrups ,where using U bars is the most practical way for providing developed bars in the construction field , for vertical bars Ash was using 2 T16 L-shaped bars and Ah was used 1 T10 U bars **Figures 2.5**, **The Sample 4R reinforcement As, Ash provided as per the common field practice to determine whether these details could vary the shear capacity than RFT details of sample 2**

In Sample 4R was changing the anchorage of the inclined bars from bent bars to extended bars welded to steel plate **Figures 2.7**

Test setup and instrumentation

The four specimens were tested under a using a hydraulic jack having a compressive axial load capacity of 1,390 kN (see Fig. 2.10),. The supports of the beam were composed of a steel roller of diameter of 50 mm, and steel box section as hinged support. The rollers permitted the beams to elongate and rotate at their ends. For the bearing, one steel plate of 200 x 150 x 50 mm was set under the hydraulic jack and the load cell at 800mm from tested side of the beam. The same size of steel plates as the anchorage steel plates in the nibs were located at the support points., the bearing plates, rollers, and steel Box section were carefully positioned during testsetup.

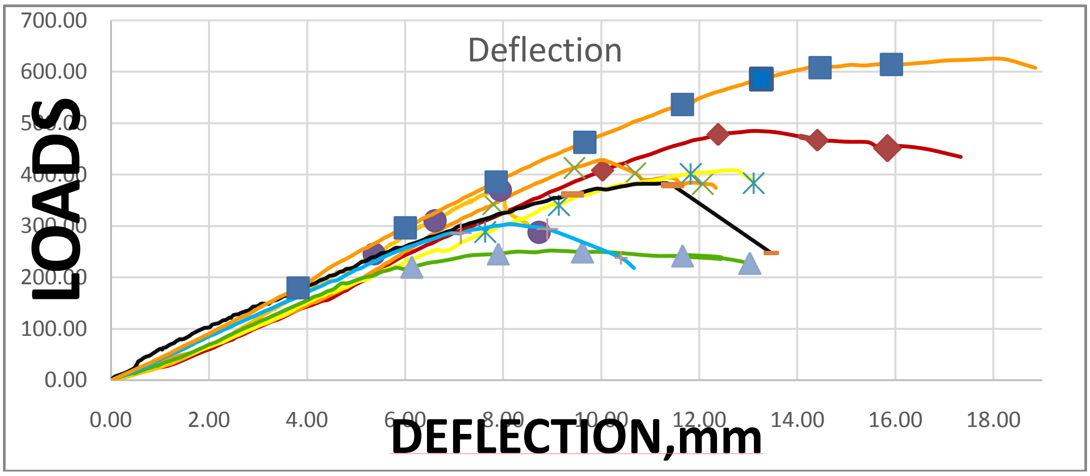


Test Results

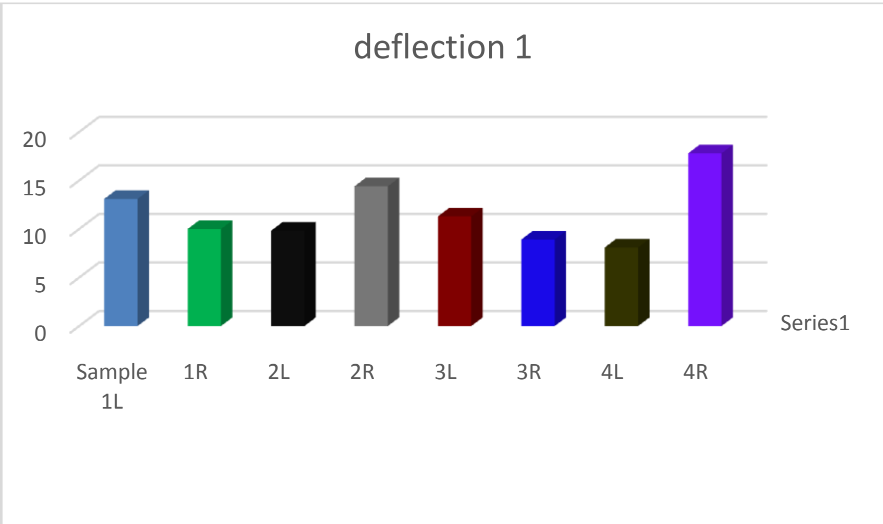
The performance, including end deflections, strain, and applied loads, was monitored and recorded

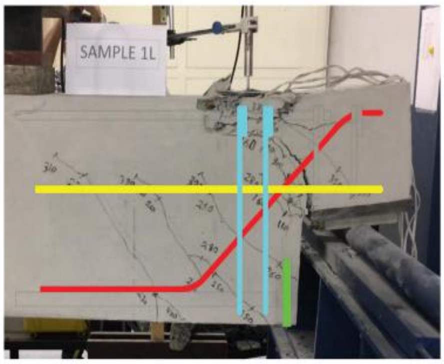
Test program included testing eight dapped-ends beams, as mentioned before, under the load that has been applied incrementally up to failure stage. Test results were classified to attain a better understanding for the beams dapped-end response and behavior. These are;

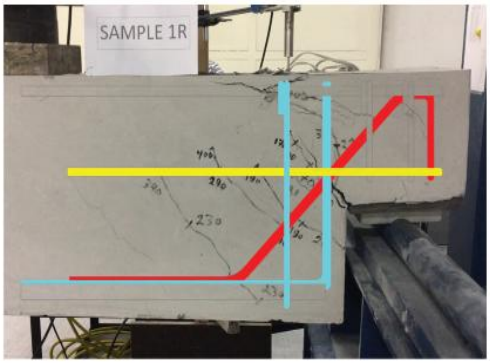
- Crack pattern,
- load capacity, and
- mode offailure.
- Load
- strainrelations.

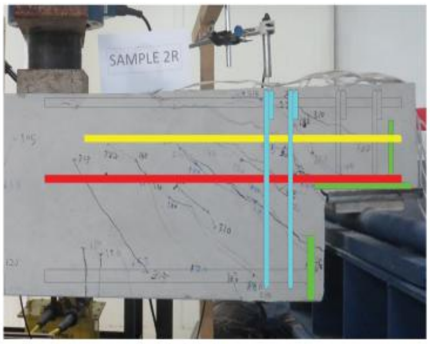


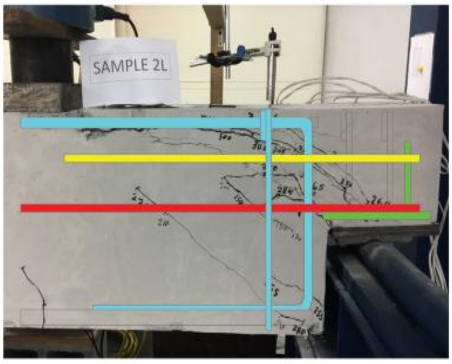
- Load- deflectionrelations.











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